Fermi National Accelerator Laboratory

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Flying Wires at Fermilab *

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Summary

Transverse beam profile measurement systems called "Flying Wires" have been installed and made operational in the Fermilab Main Ring and Tevatron accelerators. These devices are used routinely to measure the emittance of both protons and antiprotons throughout the fill process, and for emittance growth measurements during stores. In the Tevatron, the individual transverse profiles of six proton and six antiproton bunches are obtained simultaneously, with a single pass of the wire through the beam. Essential features of the hardware, software, and system operation are explained in the rest of the paper.

Introduction

A Fermilab "Flying Wire" is a device that passes ("flies") a 25 micron carbon filament through a particle beam, transversely, at a constant velocity of between two and five meters/second. Collisions between the beam particles and the wire produce secondary particle cascades, which in turn produce photons in a scintillator. A photomultiplier tube and an optical encoder are used to measure the light intensity and the wire position, respectively. A light intensity vs transverse position plot may then be obtained, from which the beam width is determined. Two wires in the horizontal plane and one wire in the vertical plane, at the appropriate positions in the lattice of a circular accelerator, enable measurements of the beam emittance.

The Flying Wire System is controlled by a 32-bit VME based microcomputer system. This system provides or controls the wire fly, data acquisition, data reduction, and statistical analysis functions. The system can fly the wire, acquire, reduce, and analyze the data, store the data in local memory, and be ready to fly the wire again in 150 milliseconds.

Flying Wire Assembly

A description of the Flying Wire System components installed in the accelerator tunnel begins with a carbon wire stretched across the opening of a low moment of inertia fork. The fork is coupled through the vacuum chamber wall using a 'ferrofluidic' rotating seal. An optical encoder is connected to this shaft to measure the angular position of the fork assembly. The fork/encoder/seal assembly is rotated by a low inertia ironless rotor DC servomotor through a speed reducing gear and belt drive system. The gear ratio is chosen to match the load moment of inertia to the moment of inertia of the motor [1]. The encoder provides an angular resolution of 0.022 degrees (16384 steps per revolution). The fork spacing and length are determined by the beam aperture at the location the wire is to be installed. A pictorial drawing of the wire assembly is shown in Figure 1. Photomultiplier tube and scintillator assemblies are placed upstream and downstream of the wire to measure antiprotons and protons, respectively.

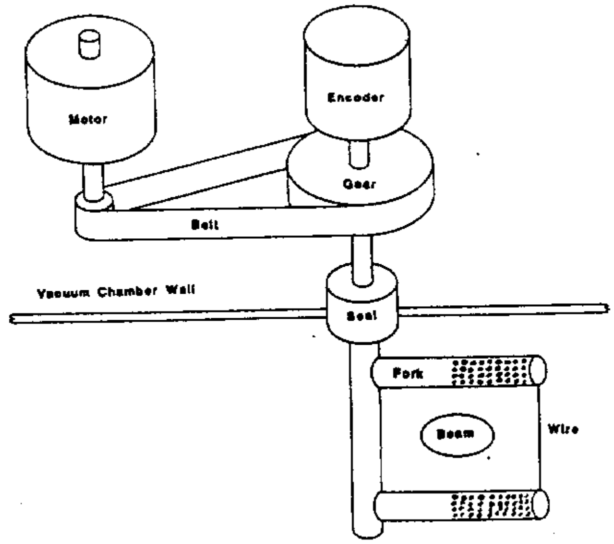

Figure 1
Pictorial Drawing of Wire Assembly

The motion of the wire is controlled by a commercial 8-bit servo controller chip set manufactured by Galil Motion Control, Palo Alto, Ca. This controller uses the encoder as the feedback element and provides an analog output signal to drive the motor through a linear voltage mode power amplifier. The wire motion follows a predetermined trapezoidal velocity profile as shown in Figure 2. The time interval of constant velocity occurs while the wire is passing through the beam aperture.

Data Acquisition

Data acquisition is synchronized with the bunch arrival time, revolution period of the beam, the passage of the wire through the aperture, and the time in the accelerator cycle when the profile is to be measured. The amplitude signal from each phototube is processed, up to six times each machine revolution, with a gated integrator, digitized with a 12-bit high speed A/D convertor, and stored in a sixteen kilobyte FIFO memory. The position of the wire is also stored in another FIFO memory each time an amplitude measurement is made. The energy and intensity of the particle beam, the date, and the time of day are also recorded locally each time the wire is flown.

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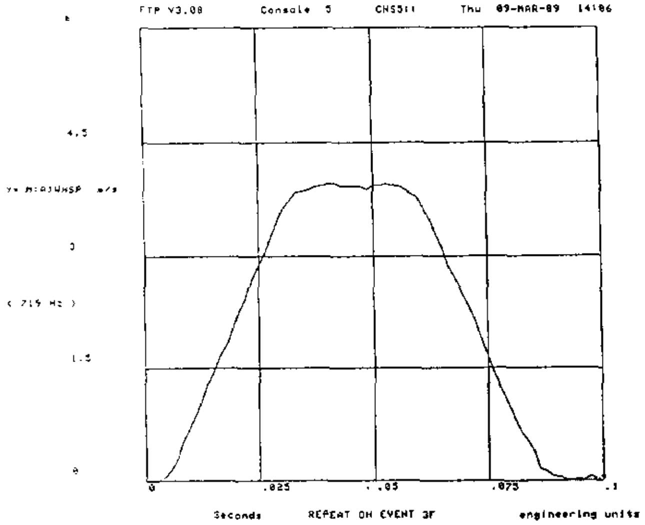

Figure 2
Typical Tevatron Wire Velocity Profile

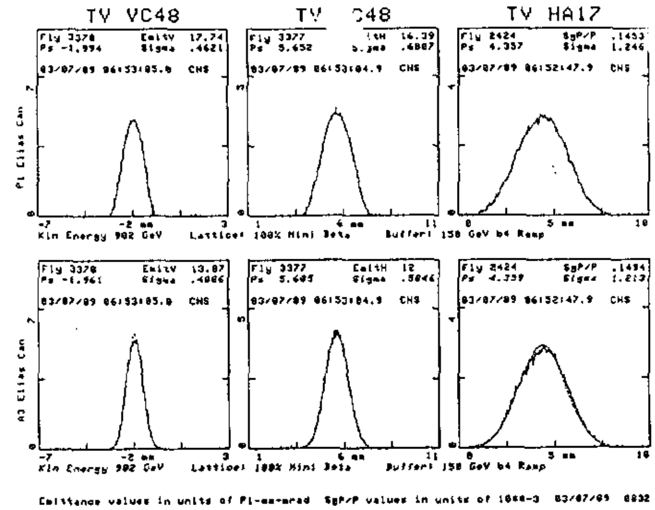

Figure 3
Tevatron Proton & Antiproton Profiles

Data Reduction and Analysis

After the the wire has been flown through the beam, the data in the FIFO memories are read out, processed into individual profiles, and stored in local memory. The 32-bit processor then calculates and stores the first three statistical moments of each profile: the area, mean, and rms deviation from the mean. The data are then available for display or further analysis at the accelerator control consoles. Data for as many as 32 flies of the wire are stored locally.

System Operation - Colliding Beams Mode

When the accelerator complex is in operation for "Colliding Beam Physics" the wires in the Main Ring and Tevatron are flown frequently. Each time a proton or antiproton bunch is accelerated in the Main Ring and injected into the Tevatron, the Main Ring wires are flown three times and the Tevatron wires are flown once. The Tevatron wires are also flown four times during the acceleration and "low beta squeeze" portions of the machine cycle and every two hours during a store.

These flies are initiated by the "Colliding Beam Sequencer" program, operating on one of the accelerator control consoles, and are synchronized by clock events that occur at predetermined times in the accelerator cycle. Other console level programs then automatically read and record the statistical parameters from the local Flying Wire microcomputers and calculate and record emittances in the accelerator control system data base.

A typical set of profiles from one of six proton and one of six antiproton bunches, in the Tevatron, are shown in Figure 3. These data were taken 17 hours into a 900 GeV store for colliding beam physics. The proton profiles are the top set of profiles.

System Operation - Fixed Target Mode

During fixed target running the wires are used in a different manner. They are not flown automatically by a console program, but are flown at times in the accelerator cycle determined by an operator or accelerator physicist. These flies are generally for the purpose of measuring either the accelerator energy at which intermittent transverse beam instabilities begin or for measuring beam size and emittance during slow extraction.

Electronics Hardware

The data acquisition electronics, the commercial 68020 32-bit microprocessor and two megabyte memory boards, and servo controllers are housed in a rack-mounted VME crate. The power amplifier for the motor and the high voltage supplies for the phototubes are housed in separate chassis. The system is connected to the accelerator control system via a microprocessor controlled CAMAC interface.

Software

The extensive and complex local software, which initiates wire flying and controls the data acquisition and reduction, is downloaded from one of the central control system computers. Specification menus ("Fly Specs") are also downloaded for each wire fly, that include timing, clock events, high voltage settings, and other pertinent parameters.

The real time control program, resident in the local microcomputers, is written in the "C" language and compiled into executable form on a separate computer system. The code is then transferred to a control computer system ("Host"), and downloaded to the local systems. A flow diagram of this software is shown in Figure 4.

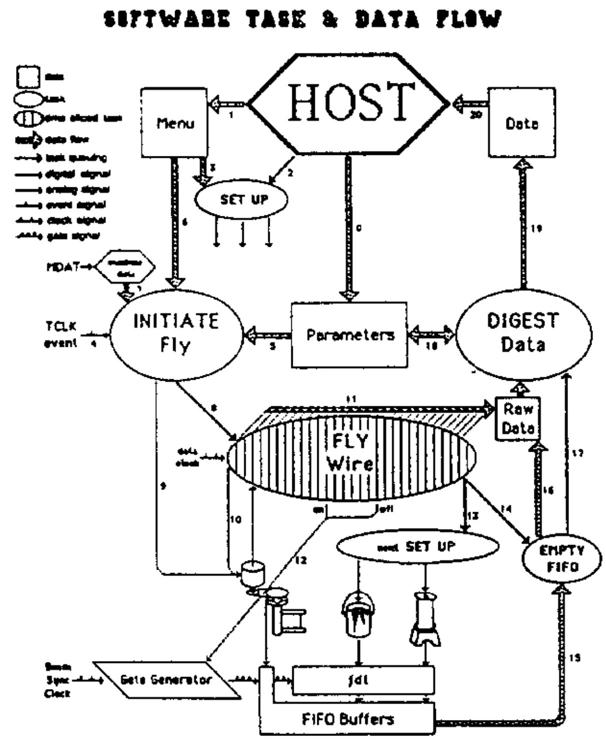

Figure 4
Microcomputer Software Flow Diagram

Referring to figure 4 , static parameters are initially set (0) from the host, which also supplies (1) a menu of fly sequence details. This sequence is activated (2), and first used, to set up (3) the fly so that the proper clock event triggers it (4). The fly is influenced by general static parameters (5), specific Menu parameters (6), and real time machine data (7). A 2 KHz time sliced motion monitor task is started (8) and the motor is prepared (9) for triggering (10). The motion monitor gathers (11) motion data during the fly. It also controls (12) the beam sync bunch gate generator by turning it on when the wire first enters the beam aperture and turning it off when it leaves. The gate generator strobes position and integrated intensity information into the FIFO buffers. When data acquisition is complete, set up is triggered (13) for the next fly (14). The FIFO buffers are immediately emptied (15) into (16) raw storage so that the data can later be analyzed (17), in conjunction with (18) static parameters, and stored (19) as digested data, to be read (20) by the host.

As noted above, the fly specification menus are created and modified from the interactive consoles in the Main Control Room. The same console-level software is also used for displaying the beam profile data from the Flying Wire system measurements.

Future Systems

Flying Wire systems for the Booster Accelerator and the Antiproton Source are under design and construction and are planned to be implemented during the next year.

Conclusion

Use of the Flying Wire systems has become an integral part of colliding beam operations at Fermilab. The wires are used daily, as diagnostic devices, during preparations for collider operation. Results from the wire measurements, along with other data and measurements, are used to determine whether the machines are ready to accept antiprotons from the Antiproton Source. They are also used extensively during accelerator experiments and studies to improve machine performance. Many types of transverse beam properties may and have been observed with these devices.

References

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